

The Single Crew Module Concept for Exploration

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Many concepts have been proposed for exploring space. In early 2010 presidential direction called for reconsidering the approach to address changes in exploration destinations, use of new technologies and development of new capabilities to support exploration of space. Considering the proposed new technology and capabilities that NASA was directed to pursue, the single crew module (SCM) concept for a more streamlined approach to the infrastructure and conduct of exploration missions was developed. The SCM concept combines many of the new promising technologies with a central concept of mission architectures that uses a single habitat module for all phases of an exploration mission. Integrating mission elements near Earth and fully fueling them prior to departure of the vicinity of Earth provides the capability of using the single habitat both in transit to an exploration destination and while exploring the destination. The concept employs the capability to return the habitat and interplanetary propulsion system to Earth vicinity so that those elements can be reused on subsequent exploration missions. This paper describes the SCM concept, provides a top level mass estimate for the elements needed and trades the concept against Constellation approaches for Lunar, Near Earth Asteroid and Mars Surface missions.

Nomenclature

ATCS	=	Active Thermal Control System
ATLETE	=	all-terrain hex-legged extraterrestrial explorer
CAMRAS	=	CO ₂ and Moisture Removal Amine System
CEV	=	Crew Exploration Vehicle
CCDev	=	Commercial Crew (vehicle) Development
CLLS	=	Closed Loop Life Support
Cx	=	Constellation (Program)
CO ₂	=	carbon dioxide
CPS	=	cryogenic propulsion stage
DRM	=	Design Reference Mission
DSH	=	Deep Space Habitat
ECLSS	=	Environmental Control and Life Support System
EMU	=	extravehicular mobility unit
ESA	=	European Space Agency
ETDD	=	Enabling Technology Development and Demonstration
ETE	=	Environmental Control and Life Support; Thermal Control; and ExtraVehicular Activity
EVA	=	extravehicular activity
FY	=	fiscal year
GEO	=	geosynchronous Earth orbit
H ₂	=	hydrogen
HEFT	=	Human Exploration Framework Team
HEO	=	high-Earth orbit
HLV	=	heavy-lift launch vehicle
HX	=	heat exchanger
IAWG	=	International Architecture Working Group
ISP	=	Interplanetary Space Propulsion (system) (a high Isp rocket system for space only use)

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ISRU	= in-situ resource utilization
ISS	= International Space Station
LCCR	= Lunar Capability Concept Review
LEO	= low-Earth orbit
LER	= lunar electric rover
LLO	= low-lunar orbit
LMO	= low-Mars orbit
LP	= Lagrangian point
LSS	= Lunar Surface Systems
MMSEV	= multi-mission space exploration vehicle
MPCV	= multipurpose crew vehicle
NC	= nominal correction
NEA	= near-Earth asteroid
NEO	= near-Earth orbit
O ₂	= oxygen
OAB	= Orbiting Assembly Base
PLSS	= Primary Life Support System
POD	= point of departure
PVR	= photovoltaic radiator
REM	= robotics and EVA module
SCM	= Single Crew Module (for transit to a destination, surface operations and return to Earth orbit)
SEP	= solar electric propulsion
SEV	= space exploration vehicle
SLS	= Space Launch System
SPR	= small pressurized rover
TCS	= Thermal Control System
TRL	= technology readiness level
USL	= U.S. Laboratory
VASIMR	= variable-specific-impulse magneto-plasma rocket

I. Introduction

When humanity goes to Mars and other exploration destinations the approach employed will affect the success of the endeavor. Combining the best ideas for the technology with an efficient approach is most likely to result in mission success.

Deep space missions require that the crew be supported in transit and at deep space destinations for long durations. The single crew module (SCM) concept (illustrated in Figure 1) recognizes that crew support requirements for transit and while at a destination are roughly the same and thus could be addressed with a single module. Fueling (or refueling) and assembly of an exploration vehicle near Earth makes the SCM concept feasible. The use of Regenerative ECLSS would minimize the mass to support the crew and an efficient Interplanetary Space Propulsion (ISP) system would minimize fuel required.

The end of a SCM mission results in the Interplanetary Space Propulsion (ISP) system and the SCM being returned to the near Earth staging site. Those core elements are to be refurbished and refueled in space then reused for subsequent exploration missions.

Such an approach to space exploration would focus exploration development on the fewest possible number of exploration elements (the SCM and ISP) and enable reuse to provide a human exploration infrastructure that can address many exploration goals. A campaign of exploration missions using the SCM approach should be more quickly achievable and much more affordable.

This paper provides a description of the SCM concept, a qualitative assessment of the benefits of the SCM approach, a comparison of the SCM with recent concepts for conducting exploration missions and a recommendation of forward work needed to establish the benefits of the SCM approach.

Background

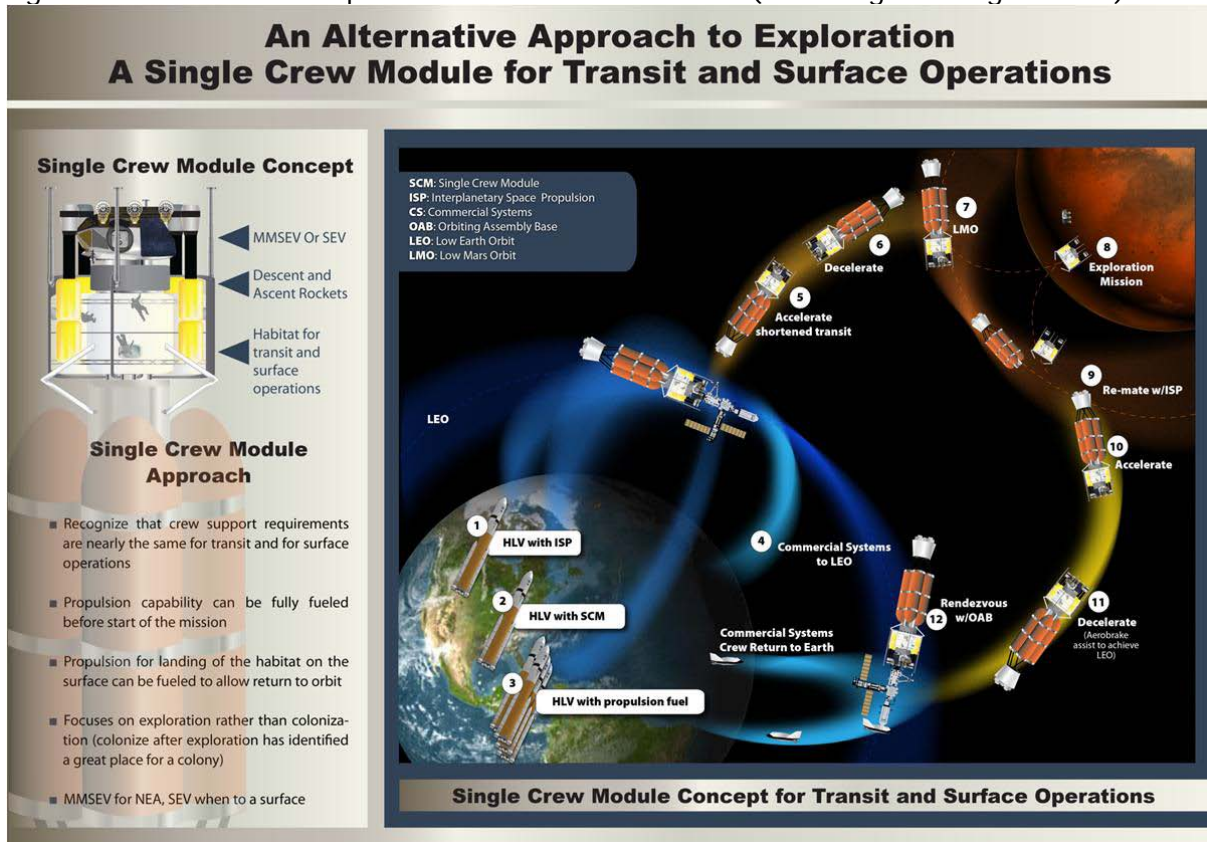
The SCM concept was first communicated to the NASA Human Exploration Framework Team via an Email in June 2010. It was proposed as a game changing concept to the NASA Office of the Chief Technologist in September 2010 (ref 1). It has been presented at Innovation Day in May 2011 and at a Knowledge Capture forum in June 2011 at Johnson Space Center.

The Presidential Budget proposal for Fiscal Year 2011 (ref 2) contained several concepts that (if realized) can be used to improve the way deep space missions are conducted. It also directed NASA to focus on deep space missions including a mission to a Near Earth Asteroid (NEA) and ultimately to conduct a human mission to Mars.

The SCM concept of a different approach to crew accommodations and mission conduct puts the new concepts together in a way that can make exploration more efficient, less costly and nearly eliminate the waste of mission resources.

The concepts SCM combines are: Commercial Crew Development (CCDev) (or Orion) access of crew to Low Earth Orbit (LEO), Heavy Lift Vehicle (HLV) launch of large payloads (now funded as the Space Launch System (SLS) Program), fueling (later refueling) (and assembly) in space, Closed Loop Life Support (CLLS), interplanetary space propulsion (probably nuclear powered), green technology (reuse mission assets and likely use of Liquid Methane as the SCM propellant), possible aerocapture and International Space Station (ISS) utilization. As of 2012, all of those new technology and vehicle efforts are being pursued by NASA as currently funded projects or in future plans. The CCDev, Orion and SLS projects are well underway.

Figure 1 - The SCM concept for a Mars Surface mission (the design driving mission)



II. SCM Module Overview

The habitat module of the SCM concept will need to address all life support and crew habitability and command functions for each entire exploration mission. The SCM module must provide enough volume for the crew to function during the long zero gravity (or very low acceleration of the ISP) of the transit phase and the long duration surface exploration phase in the partial gravity of Mars or the Moon. Cabin leak and other contingencies must be addressed.

To enable exploration at the destination mobility is required. Including a Multi-Mission Space Exploration Vehicle (MMSEV) addresses the need to address contingencies and provides both exploration mobility and Extravehicular Activity (EVA) capability.

The design driving case is a Mars landing which requires that the habitat be equipped with propulsion capability to descend from Low Mars Orbit (LMO) to land at a designated exploration site then ascend back to LMO to rendezvous with the ISP. The vehicle that addresses the Mars surface exploration mission would be capable of missions to Near Earth Asteroids (NEAs), the Moon or Mars.

The CLLS life support, thermal control, EVA, habitation, and command and habitation capabilities needed to support the crew during the entire mission need to be as efficient as possible to minimize mass of both equipment and consumables. The CLLS will minimize waste products which will partially address planetary protection issues. Planetary protection would also need to be considered for containment of samples and equipment that is used on the Martian surface. The CLLS implemented will have to address the most demanding of the environments whether that occurs in transit or during surface operations.

Transit times for NEA and Mars missions will be many months as will exploration periods on Mars. Long duration missions have been shown in exploration trade studies to greatly benefit from regenerating resources and the longer the mission the more beneficial regeneration of resources becomes. A single habitat and command module will take advantage of the benefits of regenerative for the entire duration of the mission. The most reliable solution will be employed combined with appropriate redundancy and sparing.

EVA capabilities will be required at the exploration destination. EVA interfaces would need to be robust to address the dust environment and provide the isolation needed for the crew from potential Martian contamination. The suit port concept would provide very efficient EVA capability and would address the dusty environment. The same EVA system can address potential contingencies during transits and at the destination.

Thermal control radiators must address the peak heat loads in transit and at Mars. Radiators that work efficiently in deep space may also work well in a convective Martian atmosphere.

For the lunar and Mars missions, landing gear is required. To reduce return mass the landing gear could be detached and left on the surface.

If the SCM propulsion system is provided in four modular rockets attached to the habitat in space (as shown in Figure 2) it would provide contingency capability to address one engine failure during descent or ascent at the destination. Using 4 separately controlled rockets provides redundancy to enable completion of a landing or an abort capability at the destination. Liquid Methane/Liquid Oxygen (MOX) propulsion is probably the best candidate for long duration exploration missions since long term storage of those propellants is feasible (long term storage of Liquid Hydrogen is problematic due to the extremely low (around 20 deg K (-423 degrees F) storage requirement). Thermal conditioning via deep space cooling can address the Liquid Methane (approximately 111 K (-259 F)) and Liquid Oxygen (90 K (-297 F)) storage requirements. Cryo-coolers may be required to address storage thermal conditioning while at either the Moon or Mars.

Positioning the SEV at the front end of the SCM provides radiation protection while in transit both to and from the destination. It also addresses access to the destination surface since it will be near to the surface after landing. Lunar surface systems studies identified a significant problem associated with getting mission elements from the top of the descent stage to the surface. The SCM mounting of the SEV between landing gear also effectively addresses that issue.

Propellant tanks surrounding the habitat provide a significant high quality radiation barrier. It is likely that the SCM propulsion system would be detached from the SCM after rendezvous with the ISP to minimize mass of the return vehicle back to Earth. To reuse the SCM a fueled set of SCM rockets would be provided to enable the next exploration mission. During the course of mission operations the accumulation and processing of waste products may address radiation protection for the return to Earth part of the mission (after SCM propellant has been exhausted).



Figure 2 – SCM Propulsion, SEV and ISP Provide Radiation Protection for the Habitat

Prior Constellation exploration scenarios to the moon or Mars require a propulsion system that must deliver a long duration habitat for crew occupation to the surface. The difference is that the SCM requires that the habitat be returned to orbit to rendezvous with the ISP. Recognizing that the propulsion system of planned Cx missions (which has been assessed to be feasible) had significant capability; the difference is in the amount of fuel the SCM propulsion system requires to perform the ascent. Considering that the landing gear is probably left on the surface, the difference in mass is probably within the propulsion system capability to accommodate.

For the SCM it is critical to return the habitat module and the MMSEV to orbit then back to Earth since both of those are essential for crew support and potential contingencies.

The Interplanetary Space Propulsion (ISP) system efficiency is critical to the feasibility of deep space exploration. Chemical propulsion can work but the mass required is very high. If electric propulsion technology development efforts are successful, that technology promises to provide a dramatic improvement in propulsion efficiency. Due to the dramatic specific impulse achievable via electric propulsion a factor of 10 less propellant might be required (versus chemical propulsion).

To achieve both the high specific impulse and moderately high thrust desired for deep space transit; high power is required and that probably requires that nuclear (versus solar electric) power be employed. If thrust levels are high enough dramatic changes in mission planning are achievable:

- 1) Gravity assisted processes might become feasible during transit.
- 2) Gravity related health concerns may be alleviated and the crew would be better able to conduct exploration at destinations.
- 3) The time required to reach destinations will be less and different trajectories can be considered.
- 4) The length of time the crews are exposed to space radiation is reduced alleviating concerns of long duration radiation exposure.

Technology Assessments

The SCM concept will provide robust closed loop life support closely linked with efficient EVA capabilities to minimize consumables usage.

Many options are possible for the technologies involved in specific parts of each deep space mission. The new Advanced Exploration Systems Program and Office of Chief Technologist efforts will verify that new technologies to be used are ready to make the new vehicles robust and efficient in accomplishing mission goals.

Near Earth assembly of SCM mission Elements

The SCM concept assumes that the capabilities developed during the assembly and operation of the ISS can be used to address assembly of exploration vehicles. Thus the focus of the SCM concept is on the vehicle that leaves the vicinity of Earth, conducts exploration missions and returns to the vicinity of Earth.

During the period between 1998 and 2010 the ISS was assembled and demonstrated the capability to assemble large integrated structures in space. That capability could be employed to create a base to assemble and fuel SCM modules. It is envisioned that a US photovoltaic module linked with a US laboratory module with Canadian robotic capabilities and probably a Russian Service Module would provide the capability to assemble the SCM. Such an assembly base would be placed in a location near Earth that maximizes the payload delivery capability of the HLV. The ISP, SCM modules would be delivered and assembled and then fueled at that base to enable starting exploration missions. Once fully outfitted and fueled, the crew would be launched via CCDev (or Orion) to ingress the vehicle and begin the exploration mission.

During the long duration exploration missions, the assembly base capabilities could be used for other purposes. The facility could be used for commercial or government (for example for such the development of power satellites).

It is feasible that ISS could be employed to be the location that exploration vehicles are assembled. That would provide an immediate very capable platform to begin assembly from. However, that would require that ISS be repurposed and it would require that HLV delivery of payloads be to the 57 degree inclination orbit (which reduces the mass of payload that can be delivered (versus lower inclination orbits)).

Reuse of mission assets

The approach can be used to conduct missions to asteroids, the Lunar or Mars surface or other deep space exploration destinations (all using one vehicle sequentially!).

The reuse of SCM assets requires that the ISP and SCM habitat be returned to the vicinity of Earth so that the crew can be transported back to Earth via CCDev or Orion and so that those mission assets can be refurbished, refueled and reused. Returning to the vicinity of Earth requires that the ISP decelerate the vehicle to return to the assembly base.

A potentially more efficient alternative is to use aerocapture to do much of the deceleration to return to Earth vicinity. A trade of the ISP propellant saved via use of aerocapture versus the weight of the aerocapture system would need to be conducted to establish the benefit. It is unlikely that aerocapture would be effective for slowing down at Mars due to the low atmosphere pressure.

At the end of a SCM mission the ISP system and the SCM (both nearly empty of fuel) are at the orbiting assembly base. The SCM would include the habitat and the MMSEV so both of those modules would be available for reuse. After a lunar or Mars surface mission the SCM landing gear would be left on the surface and would thus need to be replaced. Those core elements could be reused for subsequent exploration missions. The SCM propulsion system propellant tanks would be replaced as units probably including the rockets for each of the 4 to perform the next surface mission.

A challenge for the SCM is the durability of the habitat module and the ISP. It is not clear how formidable that challenge will be. However, each element in the Cx must operate for long periods of time; so the added duration associated with subsequent flights is a challenge but is probably achievable.

The clean-up of the SCM and the refurbishment of equipment at the assembly station could address life limit concerns. Clean-up and refurbishment and refueling operations could be contracted to commercial organizations.

Recommended Order of Missions to Build Confidence Before a Mars Mission

Each SCM mission would implement the following mission scenario:

- 1) Assemble and fuel the mission elements near Earth
- 2) Check out all and fully fuel each element at the in-space assembly station then deliver the exploration crew to man the vehicle via CCDev or Orion vehicles
- 3) Transit to the deep space destination via the ISP system to achieve low orbit around the destination
 - a. Accelerate roughly $\frac{1}{2}$ the way to destination then decelerate the rest of the transit to achieve Low Orbit at destination
 - i. Potentially use aerocapture assist to decelerate at destination to aid in achieving low orbit
- 4) Separate the SCM with its propulsion system from the ISP system
- 5) Use the SCM propulsion system descends and lands at the exploration site on the destination surface
- 6) Conduct surface operations using the SCM as the base of operations (this is what it is all about)
- 7) Ascend to low destination orbit via the SCM propulsion system and rendezvous with the ISP system
 - a. Discard the SCM propulsion system after remating with the ISP system
 - i. to reduce return mass
 - ii. possibly discard only the prop tanks to retain the engines for reuse
- 8) Use the ISP system to return to Earth vicinity orbit
 - a. Accelerate roughly $\frac{1}{2}$ the way to Earth then decelerate the rest of the transit to Earth vicinity
 - i. Potentially use aerocapture assist to decelerate to achieve Earth orbit
- 9) Rendezvous with the in-space assembly base
- 10) Transfer crew to CCDev (or Orion)

11) Use CCDev (or Orion) to return crew and samples to Earth

Human exploration of Mars is the design driving mission and the SCM approach to that mission is illustrated in Figure 3.

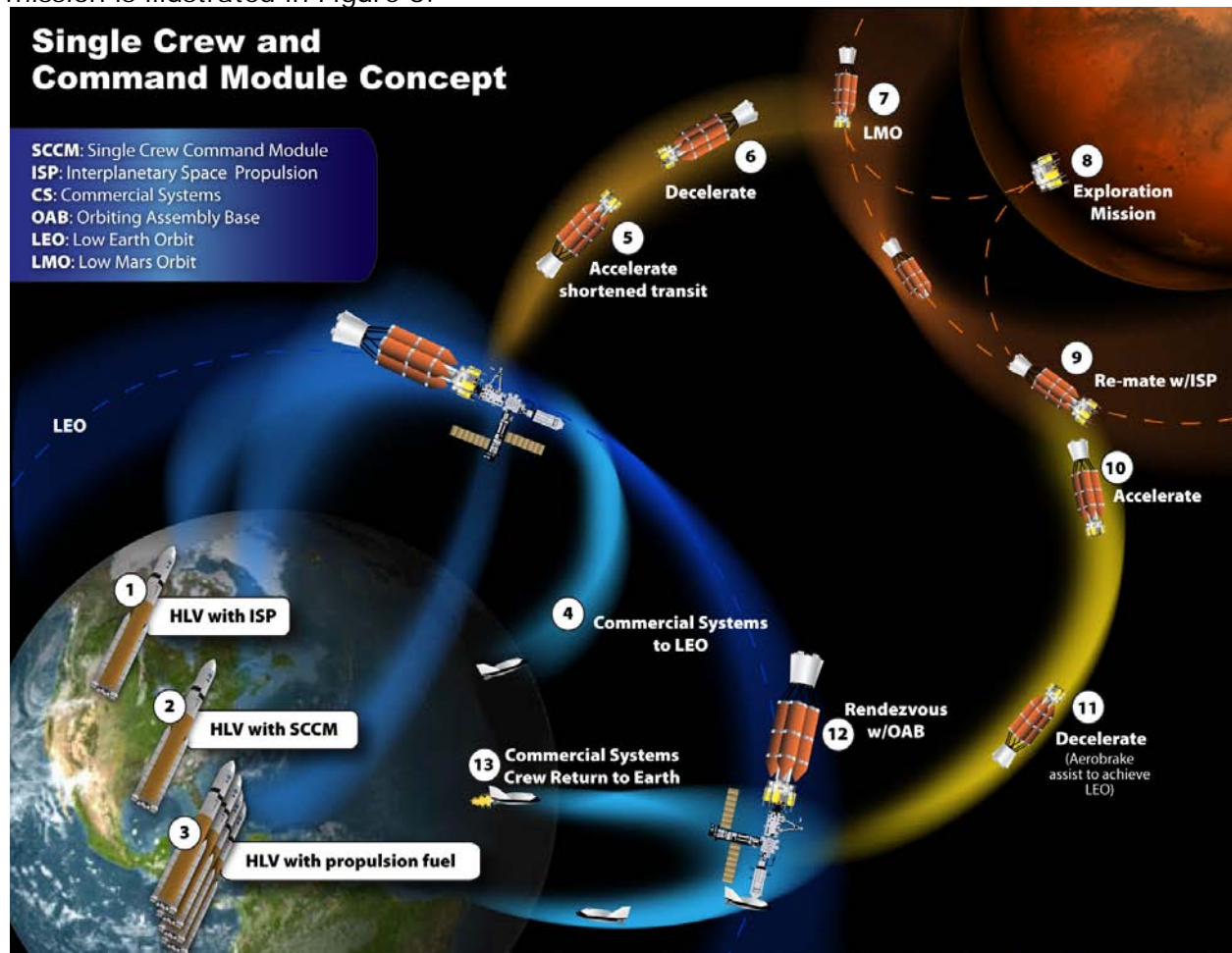


Figure 3 – Illustration of the SCM approach to the design driving Mars mission

A logical progression of missions using the SCM concept would be to: Develop the SCM habitat and ISP (designed to conduct the most challenging Mars surface mission); conduct a NEA rendezvous mission; refurbish and resupply the ISP and SCM at a near Earth site; conduct a lunar mission to test the capabilities for a Mars mission; refurbish and resupply the ISP and SCM again at the near Earth site; conduct the Mars mission. In a little more detail:

- 1) Use the ISP/SCM to conduct a NEA rendezvous mission
- 2) At the near Earth assembly base:
 - a. Refurbish and resupply the SCM habitat
 - b. Replace (or retrofit) the NEA mission Multi-Mission Space Exploration Vehicle (MMSEV) with a Surface Exploration Vehicle (SEV)
 - c. Attach a fueled propulsion system to the SCM for descent and ascent to/from Mars low orbit,
 - d. Refurbish and Refuel the ISP
- 3) Conduct a lunar mission to test the capabilities for a Mars mission
 - a. Return to the assembly base
- 4) Again at the assembly base

- a. Refurbish and resupply
 - b. Refuel the ISP
 - c. Replace or refuel the SCM propulsion system
- 5) Conduct the Mars mission.

Cost Trades

The SCM concept should save a significant amount of mass-to-destination when the entire mission is considered (versus Apollo or Constellation approaches). The SCM concept would streamline the set of vehicles and thus development needed for all exploration missions and eliminate the need for separate vehicles (such as surface Habitat, descent and ascent modules) for many exploration missions. Fewer elements of exploration missions should result in a streamlined, focused development. Development of fewer vehicles should reduce the schedule to start exploration. Reusing mission assets for subsequent missions will reduce the cost and schedule for other exploration missions dramatically. Efficiencies in development organizations needed and the cost to conduct missions will be realized.

The in-space assembly base (maybe ISS but more likely ISS derived) could be used to support Earth orbit and other Earth vicinity (Lagrangian or Lunar) NASA or commercial activities between exploration missions.

The SCM concept would be used for exploration but not for colonization since no base infrastructure would be left behind. Once exploration has established targets for colonization or conduct of business; the Cx Lunar Surface Systems (LSS) concepts should be used to meet colonization and/or commercialization needs.

III. The approach for evaluating the SCM Concept

Trade studies have been initiated to evaluate the overall mission benefits of the SCM concept (with the propellant needed for ascent from Mars) versus separate transit, descent and ascent and surface habitats. The trades will eventually establish an estimate for the overall mission mass needed to conduct an exploration mission to Mars.

The SCM concept should include estimates for the ISP, the SCM (including the SCM propulsion system) to accomplish the Mars mission (described earlier).

To establish the feasibility of the SCM concept, crew volume needed for long duration missions combined with the current mass estimates for a SEV and Landing gear mass from Cx Altair have been used to estimate the SCM mass. Much of that information can be derived starting from LSS or more recent Human Architecture Team (HAT) studies. An estimate for the habitat from HAT studies of the May 2011 Deep Space Habitat is relevant:

- a. Total Habitat mass for a 4 crew 365 day mission is 27,930 kg
- b. Habitat landing system –estimate based on Cx Altair estimates (est 2000 kg)
- c. SEV would be based on Lunar estimates ~ 4000 kg

Those elements result in an estimate mass of habitat, landing system, SEV of around 34,000 kg.

The SCM propulsion system would need to provide the capability to safely land that equipment then return a subset to LMO. The mass to be returned to LMO would be the habitat plus SEV or 32,000 kg since the landing gear could be left on the surface. The SCM propulsion system must be capable of delivering the 34,000 + prop system to surface then return that mass minus the landing gear and minus propellant used in the descent.

Comparing against Cx concepts for a Mars habitat the important difference is added prop required to launch the full habitat plus SEV. The thrust required is nearly the same as that required to land the habitat plus SEV. Thus no significant increase in the propulsion system thrust is required for the SCM versus the Cx Mars habitat landing system.

An estimate of the total mass of the SCM requires a calculation of the propulsion system and the required propellant. That estimate is TDB at this time. However, based on the logic presented above, the propellant system seems feasible since the added mass (versus

Cx concepts) is primarily the mass of the propellant needed by the SCM propulsion system to return to LMO.

That vehicle mass should then be used with estimates for the high ISP in space propulsion systems to estimate the thrust needed for the ISP and the amount of fuel the ISP would need to deliver the SCM to and from low Mars orbit.

Several refinements could be employed that could reduce the mass of the concept:

- 2) The habitat estimates use ISS derived Technologies for ECLSS. Studies of long duration missions considering advanced ECLSS technology have estimated that such systems can save over 1000 kg versus ISS derived technologies (for 1 year).
- 3) Use of an inflatable structure for the habitat would reduce structural mass
- 4) If ISP realizes short mission transits via use of high power high specific impulse propulsion; the consumables required for the mission would be reduced.

Comparison of SCM to past Apollo and Cx Exploration plans

The SCM concept is not directly comparable to past exploration approaches since it employs technology advances that were not considered in the past and since it reuses mission assets. The SCM approach of developing an exploration capability that can be employed for any exploration destination results in a significantly different compliment of mission assets than other approaches. SCM could be compared directly to the Cx Mars DRM mission to compare assets and thus understand the benefits. Or SCM could be compared to the elements required to conduct a Lunar sortie mission. However such comparisons would be somewhat misleading since one of the benefits of the SCM concept is the reuse of mission assets and when compared to a single mission those benefits are not considered.

The most appropriate comparison of past approaches and SCM is to compare the combination of a NEA, Lunar Landing and Mars Surface mission. After providing some information on the HAT NEA mission concept and the Cx Lunar Sortie and Mars DRMs a comparison of those Cx exploration missions versus the SCM approach is provided.

Apollo comparison

Apollo missions were severely constrained to elements delivered to Low Lunar Orbit (LLO) and by schedule. Due to those constraints, the mass of systems delivered to the lunar surface and especially those that were returned from the moon were extremely mass limited. The only mission scenario that provided the needed functionality, within the required schedule, used a descent vehicle to the surface and an ascent stage with minimal crew support to return to a waiting transit vehicle then return in the transit vehicle.

The Mars DRM mission described in Human Exploration of Mars – Design Reference Architecture 5.0 (ref 3) should be one of the standards for comparison except that concepts using planned new technologies (high Isp engines) should be used. Specifically, the ISP should be assumed for both mission concepts – thus the trade will be for the SCM and its propulsion system versus the Mars DRM mission compliment of elements except using the ISP system for interplanetary propulsion.

The level of fidelity of the trade needs to consider accomplishing the same exploration goals while at Mars. However, the 500 days on Mars should probably be shorter because the ISP provides more flexibility for shortening the transit time. Orbital mechanics will be different than the Cx Mars architecture study assumes because of the high Isp transit engine (the time between return opportunities will probably be different).

Many of the technologies could be assumed to be common so that the trade can focus on the differences between approaches to mission architecture. Those conducting the trade should develop a good understanding of each concept to ensure a valid trade is achieved before trading one versus another.

Comparison with Cx Lunar and Mars Design Reference Missions

Due to LEO and LLO mass constraints nearly all the Constellation mission scenarios involve essentially an Apollo mission approach.

The capability to assemble a vehicle in space and provide fuel in space can relax mission constraints significantly. Relaxing mission constraints can result in mission scenarios that can simplify the mission and reduce mission cost and complexity.

Constellation Lunar Sortie Scenario

Many approaches have been identified and considered for Lunar exploration. I'll present information on approaches that have been considered as the "Baseline"⁴ in the CxP and an alternative that used elements from the Baseline.

The baseline for Cx lunar sortie missions requires launch of a lunar lander (Altair) and an Earth Departure Stage (EDS) on an Ares 5 heavy lift vehicle. That was to be followed by launch on an Ares 1 vehicle with 4 crew in an Orion vehicle. Orion with the crew rendezvous' with Altair and the EDS in Low Earth Orbit (LEO) and the integrated vehicle transits to Low Lunar Orbit (LLO). The EDS is discarded after completion of the lunar transfer burn. In LLO the crew transfers to the Altair Ascent module and detaches from Orion. The crew occupies the Altair ascent stage during descent to the Lunar surface. If roving or habitation are required for the mission; a SEV and/or habitation module are launched on an Ares 5 and are prepositioned at the lunar exploration site prior to crew arrival. On the lunar surface, the crew exits the ascent module and descends from the Altair descent stage and conducts exploration/habitation on the moon. The duration of exploration is limited by the SEV capabilities to around 14 days. If a habitation module is included the duration of stay is limited by consumables and the extent of closure for systems. At the end of exploration, the crew reenters the ascent module, separates from the descent stage and returns to LLO to rendezvous with the Orion vehicle. The descent stage is left on the lunar surface. The ascent stage is discarded and allowed to impact the lunar surface. The crew returns to Earth on a direct trajectory and reenters to a splash down landing. The Orion vehicle may be reusable after the water landing but it will require substantial refurbishment of it may be discarded. The Lunar DRM scenario is shown in Figure 4.

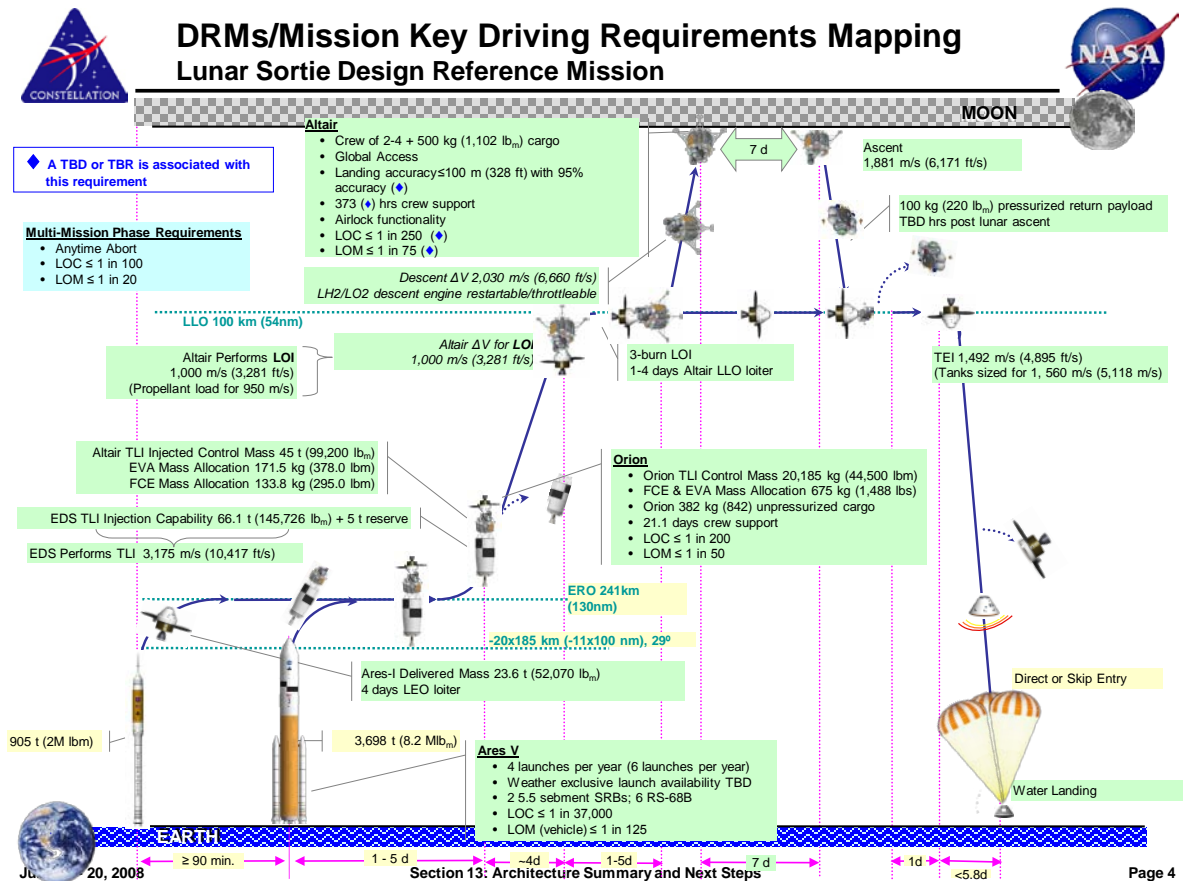


Figure 4 – Constellation Lunar Sortie Mission Illustration

LSS Scenario 10

A way to use the possibility of launching fuel to aid in lunar missions was addressed by the LSS team as Scenario 10. That scenario addressed a lunar campaign and resulted in a DRM that reused assets so that major elements were reused. It resulted in a capability to transport crew and cargo to the lunar surface with mission assets that were based in LLO where those were refueled for reuse. Scenario 10 would have resulted in program savings that proportional to the number of missions. It would result in a significant decrease in cost for a lunar exploration/colonization program by dramatically reducing the number of complex and costly descent and ascent modules required.

Cx Mars Mission DRM

The Cx Mars mission planning (Ref 3) resulted in a DRM that is feasible using current and assessed to be reasonable technology advances. That DRM (illustrated in Figure 5) includes HLV missions. The mission includes assembling mission elements for a surface habitat that is launched well in advance of the crew and pre-positioning the habitat at the Mars exploration destination. Later a transit habitation module is launched with the crew to transit to Mars and enter LMO. At LMO an Altair type of lander is used for the crew to descend to the surface to inhabit the habitat and explore. A crew only lander is used to return to LMO to rendezvous with the transit habitat.

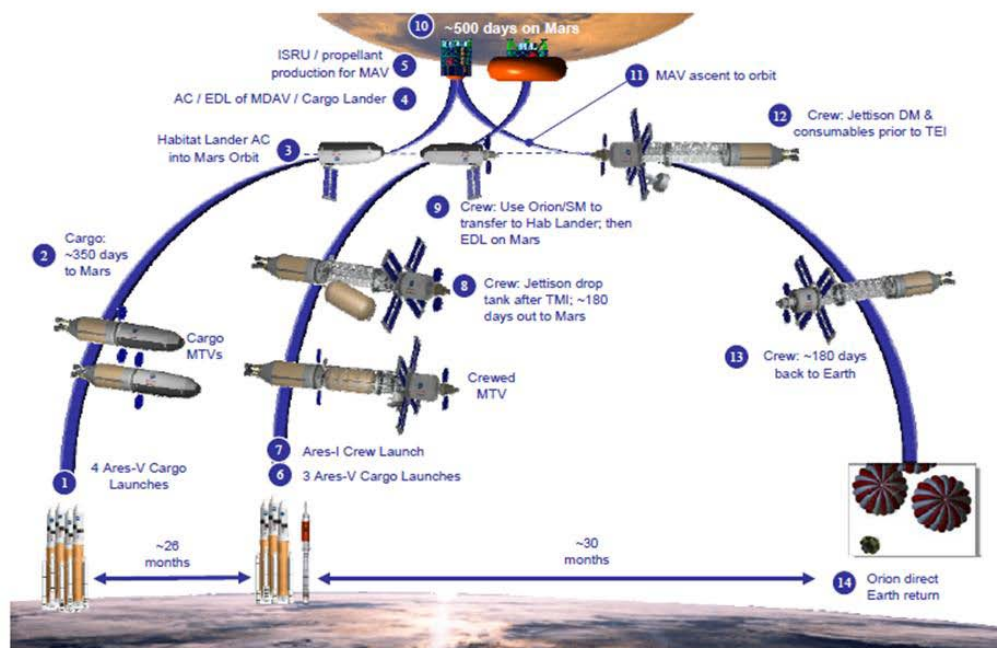


Figure 2-2. Mars Design Reference Architecture 5.0 mission sequence summary (NTR reference).

2.1 Surface Reference Mission

Several different surface architectures were assessed during the formulation of the Mars DRA 5.0, each of which

Figure 5 – The Cx DRM for Conducting a Surface Mission to Mars

Comparing Mission assets.

The Comparison of the SCM to the Cx and more recently NEA missions. Can be done qualitatively using a crew of 4 for both. The elements required for SCM versus a NEA mission and SCM versus Cx Lunar Sortie and Mars DRM are shown in Table 1.

Table	1	SCM	versus
Lunar Sortie	+	NEA	Surface
(elements departing from Earth vicinity)		+	Mars

Elements	SCM (for NEA + Lunar + Mars)	NEA	Lunar Sortie	Mars DRM
Habitat	Habitat	DSH	Orion + Lander Ascent Stage + mini Hab	DSH + Surface Hab (SHAB)
SEV	1 (MMSEV for NEA)	1 (MMSEV)	0	1
Prop	ISP	SEP + Orion	Orion + Lander + Ascent Stage	TMI (2 stages) (NTRs) + TEI (2 stages) (NTRs)
Descent or Ascent	Habitat (Descent + Ascent) (N/A for NEA)	RCS and Maneuver at NEA	Descent Module + Ascent Module	DAV (Ascent using ISRU) + DMAV + MAV
Assembly	OAS	?	Mate in LLO	?

Acronyms used for mission elements are – OAS – Orbiting Assembly Station; RCS – Reaction Control System; DSH – Deep Space Habitat; TMI – Trans Mars Injection (propulsion); NTR – Nuclear Thermal Rockets; TEI – Trans Earth Injection (propulsion); DAV – Descent and Ascent Vehicle; MAV – Mars Ascent Vehicle

The comparison that makes sense is to compare the SCM elements for the combination of the NEA + Lunar Sortie + Mars missions.

Qualifications are that the SCM propulsion system is still unquantified and the SCM refurbishment and refuel process will require launch of materials from Earth. The author speculates that NEA and Cx Mars DRM missions would also require some level of assembly near Earth prior to departure. The SCM approach of decelerating the ISP and SCM to return to Earth vicinity will require more propulsion capability than the direct atmospheric reentry planned for the HAT NEA and Cx Lunar Sortie and Mars DRMs.

The Cx DRMs require: separate crew accommodations for transit, descent, ascent and surface operations; new vehicles for every mission; prepositioning mission assets at exploration locations; (for the Mars DRM) ISRU to provide propellant for a return mission. The SCM simplifies the mission compliment of elements.

The comparison of elements required to depart from Earth for those campaigns is:

- SCM
 - Habitat (DSH), MMSEV, SEV, ISP
 - 2 refurbishment and refuel operations
- NEA + Lunar Sortie + Mars Surface
 - NEA – Orion, DSH, MMSEV, SEP
 - Lunar Sortie – Orion, Hab, Lander, Ascent
 - Mars – Orion, DSH, Surface Habitat, 2 NTRs, SEV, DMAV, MAV

The differences between the approaches are:

SCM	HAT NEA and Cx DRMs
2 refurbishment and refuel operations	3 Orions, Lander, Ascent, Hab, Surface Habitat, 2 NTRs, SEV, DMAV, MAV

The significant difference in number of mission elements required for the separate HAT NEA and Lunar Sortie and Mars missions versus the SCM approach leads to the conclusion that the SCM approach will be more efficient in conducting exploration missions.

IV. Summary of SCM Approach Benefits

[illegible]

Table 2 – Benefits of the SCM approach versus HAT NEA and CX Lunar and Mars DRM

V. Summary and Conclusion

The SCM concept has merits and could significantly simplify the conduct of exploration missions. The reuse of mission assets for subsequent exploration missions could dramatically reduce the cost of exploration and could significantly reduce the time required to develop and conduct a Mars mission. The infrastructure in the Orbital Assembly Base could be used to conduct other near Earth NASA or commercial operations between exploration missions.

VI. Forward Work

Using current calculations of the mass of the SCM habitat, the Space Exploration Vehicle (or MMSEV) and landing gear (total of 34,000 kg) the mass of the SCM propulsion system can be calculated. It is planned to use that vehicle mass to then calculate the performance required of the Interplanetary Space Propulsion (ISP) system. Using that performance and forecasts of the specific impulse that is likely to be achieved in advanced propulsion development the mass of the ISP fuel required can be calculated.

That set of calculations will complete the estimation of the total complement of the mission elements for a Mars surface mission. The SCM approach mission mass can then be compared to the mass of comparable HAT and prior Cx mission estimates. The per mission and aggregate mission masses for several exploration missions can then be compared and the approaches traded.

Given that those trades validate the advantage of the SCM approach; the next steps are normal development activities of evaluating technology options to minimize mass and improve functionality of mission elements. Technology and operational options that could lead to reduction of vehicle mass include:

- 1) Use of an inflatable habitat structure to reduce structural mass
- 2) Use of ISS as an assembly site (eliminates the need for a separate near Earth assembly base – but decreases the mass each launch can deliver to space because of the high inclination)
- 3) Use the Orion instead of the SEV for contingency and to provide direct return of the crew (without the time needed to decelerate to Earth orbit). Provides contingency capabilities and shortens crew return time. Eliminates the roving capability at the destination.
- 4) Jettison landing gear at destination surface (requires refurbishing the SCM with new landing gear for the next mission)
- 5) Jettison SCM propulsion prop tanks and maybe the engines (requires resupply of those elements for the next mission (refueling required in any scenario)
- 6) Segment the ISP prop tanks and discard tanks when empty (refueling required in any scenario)
- 7) Leave the SEV on the surface (compromises contingency capabilities during return)
- 8) Develop and fuel in LEO then transport to beyond Earth's radiation belts before crew ingress (maximizes Earth launch mass to space, minimizes crew radiation exposure)
- 9) Employ aerocapture to reduce velocity on return to Earth (minimizes ISP propellant required). Potentially use multiple skip aerocapture to address reentry loading and thermal loads.

Acknowledgments

The author gratefully acknowledges support and encouragement from the Crew and Thermal Systems division of NASA JSC specifically the division chief Patricia Petete and illustrator Jeannie Corte the planning for exploration missions done by the Constellation Program specifically the Lunar Surface Systems team lead by Chris Culbert and Gary Spexarth and the Mars DRM team lead by Brent Drake.

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